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Investigation of Filter Media for Use in the Determination of Mass Concentrations of Ambient Particulate Matter

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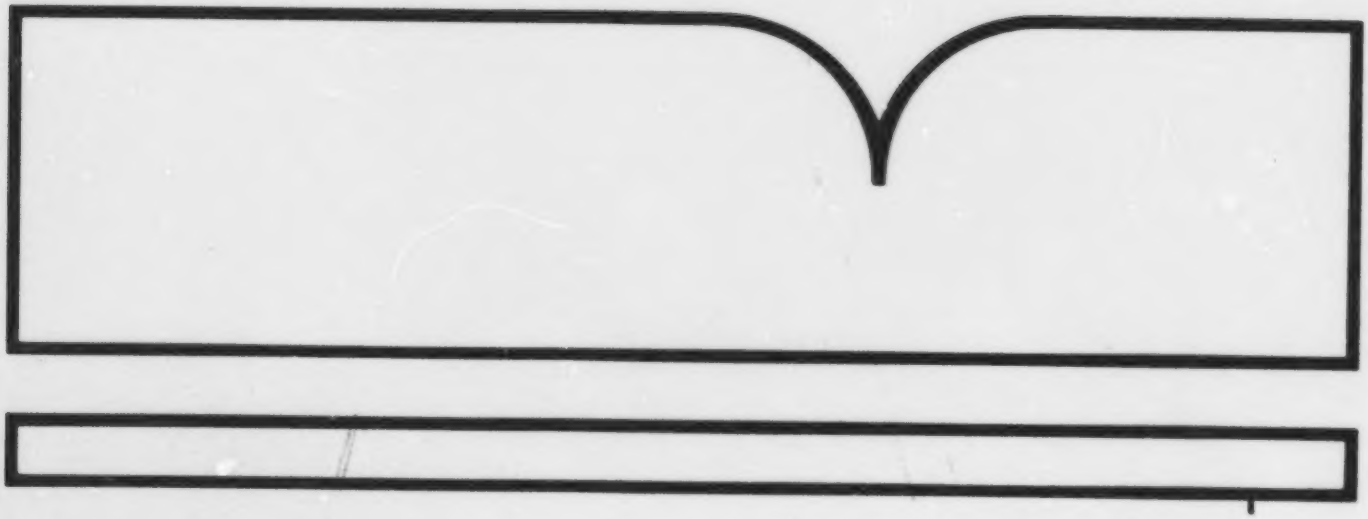

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INVESTIGATION OF FILTER MEDIA FOR USE IN THE DETERMINATION OF MASS CONCENTRATIONS OF AMBIENT PARTICULATE MATTER

by

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16. ABSTRACT

Quartz and teflon filter media were evaluated under controlled use conditions to determine their suitability for ambient particulate measurements. Weighing tests and handling tests were conducted in a laboratory environment. A field comparison test in which samples were collected on glass, quartz, and teflon filters was conducted at a typical air quality monitoring site.

An analysis of weight changes observed during repeated weighings of 8 x 10 inch and 102 mm glass, quartz, and teflon filters showed no evidence of systematic weight losses during the weighing process. Weight losses were observed for both glass and quartz filters during filter mounting and handling tests, but the estimated errors in corresponding mass concentration measurements due to such weight losses were always less than 3 $\mu g/m^3$. Teflon filters generally gained weight during these tests.

Total suspended particulate, nitrate, and sulfate concentrations measured during the field comparison test using quartz and teflon filters on high-volume samplers were lower than those measured using glass filters. Observed differences could be explained reasonably well by artifact effects and the aforementioned handling effects. Teflon filters showed a tendency to clog at ambient total suspended particulate concentrations around 75 $\mu g/m^3$.

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FOREWORD

Measurement and monitoring research efforts are designed to anticipate potential environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, NC, has responsibility for: assessing environmental monitoring technology and systems; implementing Agency-wide quality assurance programs for air pollution measurement systems; and supplying technical support to other groups in the Agency, including the Office of Air, Noise, and Radiation, the Office of Toxic Substances, and the Office of Enforcement.

As part of its environmental monitoring assessment program, the Quality Assurance Division of EMSL has evaluated a series of quartz and Teflon® filter media to determine their suitability for use in ambient particulate measurements. The use of such filters for size-specific particulate measurements is anticipated when new national ambient air quality standards for particulate matter are promulgated. Quartz and Teflon® filters exhibit lower artifact formation potential than the glass fiber filters currently used for total suspended particulate measurements; however, quartz filters are more fragile than glass filters and are subject to fiber loss during normal handling operations and Teflon® filters are subject to more rapid clogging as mass loadings increase. This report presents the results of carefully controlled laboratory and field tests designed to determine the feasibility of using quartz and Teflon® filters for particulate mass concentration measurements.

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ABSTRACT

Quartz and Teflon® filter media were evaluated under controlled use conditions to determine their suitability for use in ambient particulate measurements. Weighing tests and handling tests were conducted in a laboratory environment. A field comparison test in which samples were collected on glass, quartz, and Teflon® filters was conducted at a typical air quality monitoring site.

An analysis of weight changes observed during repeated weighings of 8 x 10 inch and 102 mm glass, quartz, and Teflon® filters showed no evidence of systematic weight loss during the weighing process. Weight losses were observed for both glass and quartz filters during filter mounting and handling tests, but the estimated errors in corresponding mass concentration measurements due to such weight losses were always less than 3 $\mu g/m^3$. Teflon® filters generally gained weight during these tests. Although the observed weight gains were small over the short time periods involved in this study, further investigation of this phenomenon is recommended.

Total suspended particulate, nitrate, and sulfate concentrations measured during the field comparison test using quartz and Teflon® filters on high-volume samplers were lower than those measured using glass filters. Observed differences could be explained reasonably well by artifact effects and the aforementioned handling effects. Teflon® filters showed a tendency to clog at ambient total suspended particulate concentrations around 75 $\mu g/m^3$.

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SECTION 1

INTRODUCTION

The most widely used methods for measuring the mass concentration of particulate matter in the atmosphere involve aerosol collection on a filter substrate and subsequent gravimetric mass determination. The current EPA reference method for determination of suspended particulates in the atmosphere (TSP) uses the high-volume sampler and a glass fiber filter for sample collection.[1] Glass fiber filters exhibit high collection efficiencies for all particle sizes,[2] are not prone to rapid overloading, have the physical characteristics to withstand the normal handling operations inherent in air monitoring network applications, and are relatively low in cost.

A major disadvantage of glass fiber filters is their inability to provide a chemically inert collection surface; consequently, artifact formation resulting from gas-to-particle conversions on the filter surface often represents a significant interference in the desired mass concentration measurement. Sulfate and nitrate artifacts, formed by the oxidation of acidic gases (i.e., SO_2, NO_2) and retention of nitric acid on the surface of these alkaline glass fiber filters, have been demonstrated by several investigators in both laboratory and field studies.[3,4,5,6] The magnitude of the resulting errors in particulate mass concentration measurements is variable and dependent upon conditions such as filter pH, sampling location and period, ambient temperature, and relative humidity. Estimates of the most probable combined errors from sulfate and nitrate artifacts range from about 7 $\mu g/m^3$ (typical sampling locations) to as high as 11 $\mu g/m^3$ (Los Angeles Basin) for a 24-hour sampling period.[7]

Over the past few years, EPA has established a nationwide inhalable particulate (IP) network to collect air quality data in support of anticipated revisions in the national ambient air quality standards (NAAQS) for particulate matter. Samplers deployed in this network include the conventional high-volume sampler and similar samplers equipped with size-selective inlets (SSI) designed to collect particles in the $\leq$ 15 μm and $\leq$ 10 μm size ranges. Although glass fiber filters continue to be used with these samplers, it is clearly evident that mass concentration errors resulting from artifact formation pose a more significant problem for the size-specific measurements than for TSP since less mass is collected in the $\leq$ 15 μm or $\leq$ 10 μm size ranges.

Consideration of available alternative filter media for these samplers indicates that quartz filters may exhibit less artifact interference; however, their use in routine sampling will depend on whether they are sufficiently rugged to withstand the normal handling operations encountered in a typical air monitoring application. Quartz filters are known to be extremely fragile and may be prone to fiber loss during weighing, handling, and sampling.

Teflon,® used as the filter substrate in low-volume (dichotomous) samplers and the recently developed medium-volume (4 cfm) samplers, is another alternative filter medium. Positive sulfate and nitrate artifact formation is not a problem with Teflon® filters; however, loss of particulate nitrate by dissociation or chemical reaction has been reported.[8,9] Physical loss of particles after sample collection[10] and static charge interferences in the weighing process can be problems. Teflon® filters are prone to more rapid clogging as mass loadings increase and are more expensive than glass or quartz filters.

This report describes an investigation undertaken by EPA's Environmental Monitoring Systems Laboratory (EMSL) to evaluate several types of commercially available filter media for their suitability for routine use with particle samplers such as those deployed in the EPA IP network. Results of a field comparison study in which samples were collected on glass, quartz, and Teflon® filters over a 12-day period are also presented.

SECTION 2

EXPERIMENTAL

FILTER SELECTION

The filters selected for evaluation are listed in Table 1. The glass fiber filters were included in the evaluation for comparison purposes.

TABLE 1. FILTERS SELECTED FOR EVALUATION

Manufacturer	Filter Type	Part No. or ID	Designation in this Report
Schleicher & Schuell	Glass fiber	(1981 SLAMS Network)	S & S
Gelman	Microquartz fiber	64988/(1979 IP Network)	Gelman(79)
Gelman	Microquartz fiber	66100/(1981 Production)	Gelman(81)
Whatman	Quartz microfibre	QM-A	Whatman
Pallflex	Tissuquartz	2500 QAST	Pallflex
Membrana/Ghia	Zefluor™ membrane	P5PI	Ghia

PRELIMINARY TEST - 8 x 10 INCH FILTERS

A preliminary test was performed to determine the magnitude of mass losses for 8 x 10 inch quartz fiber and glass fiber filters during normal handling operations. The Gelman microquartz fiber (1979 IP Network) and Schleicher and Schuell glass fiber (1981 SLAMS Network) filters were used in this test. All weighings were performed on a Mettler 5-place mechanical balance. The experimental design is outlined below:

1. Ten quartz and ten glass filters were randomly selected from available supplies for use. Loose fibers were removed with a camel hair brush.

2. The filters were placed on their lengthwise edge in two clean metal file racks and covered with clean white paper towels.

3. The filters were conditioned in a climate controlled weighing room ($\leq$ 50% RH, T = 22° ± 3° C) for at least 24 hours and weighed.

4. The filters were reweighed 24 hours later without being removed from the weighing room.

5. The filters were placed in boxes and transported to a field site (~10 miles) and individually placed on a high-volume sampler.

6. All clamps were tightened as they would be for collection of a normal field sample. (No air was drawn through the filters.)

7. The filters were removed from the sampler, folded in half lengthwise, and placed in separate manila folders.

8. The filters were returned to the weighing room and conditioned (as above) in the folders for at least 24 hours.

9. The filters were removed from the manila folders, weighed, and returned to the folders.

10. After six days of further conditioning, the filters were reweighed.

WEIGHABILITY TEST - 8 x 10 INCH FILTERS

The six types of filters were subjected to multiple weighings to determine whether significant weight losses occurred during due to the weighing process. A Mettler 5-place mechanical balance was used for all weighings. The calibration of the balance was checked with Class S-1 weights prior to the start of the filter weighings. The precision of the balance was also estimated by repeated weighing of a 5-gram standard weight. The results of these checks are given in Appendix A. The experimental design of the weighability test is outlined below:

1. Ten filters of each filter type were randomly selected for use from available supplies. Loose fibers were removed with a camel hair brush.

2. The fiber filters were placed on their lengthwise edge in clean metal file racks and covered with clean white paper towels. The Teflon® filters had to be placed in separate manila folders before placement in the rack.

3. The filters were conditioned in a climate controlled weighing room ($\leq$ 50% RH, T = 22° ± 3° C) for at least 24 hours prior to the initial weighing.

4. The filters were weighed each day for six days without being removed from the weighing room. The weighing order for the ten filters of a given filter type was on a random basis. The weighing order of filter type from day-to-day was also random.

5. The weighing sequence for each set of ten filters was as follows:

    a. Check and adjust balance zero.
    b. Check balance calibration with 5-gram standard weight.
    c. Weigh five filters.
    d. Check and adjust balance zero.
    e. Weigh five filters.

6. The weighing room temperature and relative humidity were measured and recorded during the weighings of each set of ten filters.

HANDLEABILITY TEST - 8 x 10 INCH FILTERS

The six types of filters were subjected to a handling test to determine the magnitude of weight losses due to placement on a sampler. The experimental design of the handleability test is outlined below:

1. Ten filters of each filter type were randomly selected for use from available supplies.

2. The filters were prepared for weighing and conditioned (as described above) for at least 24 hours prior to the initial weighing.

3. The filters were weighed twice on one day (morning and afternoon) without being removed from the weighing room. The weighing order was on a random basis as in the weighability test.

4. The filters were placed in boxes, transported ~ 3 miles to another laboratory, and individually placed on a high-volume sampler. The order of placement on the sampler was on a completely random basis.

5. All clamps were tightened as they would be for collection of a normal field sample.

6. Particle free air, produced by passing room air through a high efficiency particulate (HEPA) filter, was drawn through each filter for 5 minutes.

7. The filters were removed from the sampler, folded in half lengthwise, and placed in separate manila folders. The ten folders for a given filter type were placed in a manila envelope.

8. The filters were returned to the weighing room, removed from the manila envelopes, and conditioned in the manila folders for six days prior to reweighing.

9. The filters were removed from the manila folders and again weighed twice on one day without being removed from the weighing room.

10. The weighing sequence was randomized as in the weighability test.

11. The weighing room temperature and relative humidity were measured and recorded during the weighings of each set of ten filters.

FIELD COMPARISON TEST - 8 x 10 INCH FILTERS

A field comparison test using the six types of filters was conducted at the Durham Air Monitoring and Demonstration Facility (DAMDF) in Durham, North Carolina. The DAMDF is representative of a typical urban-commercial-industrial air monitoring site. The six filter types were systematically alternated among six high-volume samplers so that each filter type was used twice with each sampler over 12 sampling days.

The high-volume samplers were calibrated at the start of the field test with a flow rate transfer standard (calibration orifice unit) and four flow audits were performed over the course of the study using an independent flow audit device. The flow calibration and audit data are given in Appendix B. The six samplers were situated on the roof of the DAMDF in two rows of three samplers with six feet separation between adjacent samplers.

Two days of sampling (one before and one after the 12 planned sampling days) were devoted to estimating the between-sampler reproducibility. On these two days, ambient samples were collected using glass fiber filters on each of the six samplers.

All filters used for sample collection were randomly selected from available supplies and conditioned in a climate controlled weighing room ($\leq$ 50% RH, T = 22° ± 3° C) for several days prior to the start of field sampling. Filters for a scheduled sampling day were then weighed twice before sampling, with the second weighing performed on the morning of the sampling day. After the second weighing, the filters were placed in individual manila folders, transported to the DAMDF, and placed on the samplers. After a nominal 24-hour sampling period, the filters were removed from the samplers, folded in half lengthwise, and placed in separate manila folders. The filters were returned to the weighing room and conditioned in the folders for several days. The filters were then reweighed twice (or in some cases three times). A Mettler 5-place mechanical balance was used for all weighings.

Nitrate and sulfate analyses were performed on all collected samples, including those collected on the two days when glass fiber filters were used on all six samplers. Two 3/4 inch strips, one cut from the edge and one cut from the center of each filter, were analyzed for NO_3^- and $SO_4^=$ using an ion-chromatographic procedure.[11] All samples from a given sampling day were analyzed in the same analytical run to insure more meaningful comparisons among the filter types. Four filter blanks for each filter type were analyzed for NO_3^- and $SO_4^=$ in separate analytical runs and NO_3^- and $SO_4^=$ QC strips were analyzed during each analytical run.

HANDLEABILITY TEST - 102 mm FILTERS

The handling test (and experimental design) described above for 8 x 10 inch filters was repeated using 102 mm circular filters. For this test a medium-volume (4 cfm) sampler was used rather than a high-volume sampler.

Filters were conditioned (as described before) in individual glassine envelops with the flaps cut off. The test was conducted initially using only the Ghia Teflon® membrane filters and then repeated using all six filter types. During these tests the filters were placed between two Teflon® rings for installation on the sampler (normal installation procedure for the RAC 4 cfm sampler used for the test). A Mettler 5-place mechanical balance was used for all weighings. The precision of this balance was checked using a 1-gram standard weight. The results of this check are given in Appendix A.

WEIGHABILITY AND HANDLEABILITY TESTS - 37 mm FILTERS

A test was conducted using the four types of quartz filters and a Perkin-Elmer 5-place electrobalance to determine the feasibility of using quartz filters with low-volume samplers (e.g., dichotomous samplers). Five filters of each type quartz were subjected to various handling operations including multiple weighings, placement in nylon cassettes used in the Sierra Model 244 dichotomous sampler, drop tests, and mailing tests. For the drop tests, weighed filters were placed in the cassettes and the cassettes were placed in 50 mm petri dishes. The petri dishes were placed in a box, the box sealed, and then dropped from a height of six feet. The filters were then unpacked and reweighed. For the mailing tests, weighed filters were similarly packaged and then mailed from RTP to a location in another postal zone. The filters were hand carried back to RTP, unpacked, and reweighed. Not all filter types were subjected to the same treatment during these tests.

SECTION 3

RESULTS AND DISCUSSION

PRELIMINARY TEST - 8 x 10 INCH FILTERS

The two initial weighings of the S&S glass fiber filters gave an average difference of + 0.4 mg ± 0.1 mg (one standard deviation). All of the glass fiber filters gained weight with the largest gain being 0.7 mg, the smallest being 0.2 mg. The observed weight differences were consistent with normal humidity effects and well below the QA Handbook[12] limits of ± 2.8 mg for reweighing unexposed high-volume filters. The two initial weighings for the Gelman(79) quartz filters gave an average difference of -0.3 mg ± 0.2 mg. All of the quartz filters lost weight (-0.1 mg to -0.8 mg). The magnitude of these differences was again within normal conditioning variability but in the opposite direction of that observed for the S&S glass fiber filters. Since both filter types were conditioned and weighed at the same time, it was assumed that the Gelman(79) quartz filters did lose some weight during conditioning and weighing.

The two weighings after placement on the sampler for both Gelman(79) quartz and S&S glass fiber filters were compared and showed similar results, with the quartz filters showing an average weight gain during the conditioning period of 0.1 mg ± 0.1 mg and the glass filters showing an average weight gain of 0.2 mg ± 0.3 mg. Both of these differences can be accounted for by normal humidity variability within the weighing room.

To determine whether placement of the filters on the sampler had any effect, the average of the two initial weights was compared with the average of the two final weights for each filter type. The Gelman(79) quartz filters showed an average weight loss of 3.5 mg ± 1.1 mg, which is larger

than one would expect from normal humidity effects. The S&S glass filters showed an average weight gain of 0.6 ± 0.2 mg, which is within normal variability attributable to humidity variations. The magnitude of the weight loss for the Gelman(79) quartz filters corresponds to about 2 $\mu g/m^3$ of particulate matter (assuming 1800 m^3 sample volume). Since this effect is small relative to the estimated errors due to artifacts with glass fiber filters (7 to 11 $\mu g/m^3$), it was concluded that the use of quartz filters for high-volume particulate sampling was feasible.

WEIGHABILITY TEST - 8 x 10 INCH FILTERS

The average weight changes between successive weighings (over six weighings) and the standard deviations of the weight changes are tabulated in Table 2 for each filter type.

TABLE 2. WEIGHT CHANGES (mg) BETWEEN SUCCESSIVE WEIGHINGS (8 x 10 INCH FILTERS)

		S&S Glass	Gelman(79) Quartz	Gelman(81) Quartz	Whatman Quartz	Pallflex Quartz	Ghia Teflon®
W2-W1:*	Avg.	+0.31	-0.03	+1.88	+0.08	+0.26	-0.26
	S.D.	0.19	0.22	0.36	0.36	0.15	0.35
W3-W2:	Avg.	-0.06	+0.14	+0.05	-0.49	-0.18	+0.24
	S.D.	0.11	0.16	0.29	0.43	0.25	0.16
W4-W3:	Avg.	+0.13	-0.10	-0.98	-0.12	-0.23	+0.19
	S.D.	0.12	0.18	0.47	0.13	0.15	0.22
W5-W4:	Avg.	-0.43	-0.67	-1.67	-0.43	+0.14	+0.14
	S.D.	0.15	0.22	0.27	0.16	0.24	0.20
W6-W5:	Avg.	+0.33	-0.13	+0.81	+0.06	-0.05	-0.02
	S.D.	0.13	0.17	0.38	0.12	0.12	0.18
W6-W1:	Avg.	+0.30	-0.79	+0.10	-0.90	-0.06	+0.29
	S.D.	0.17	0.22	0.54	0.29	0.18	0.39

*W1 indicates the first weighing and so on.

The magnitude of the changes in weight for all filters were similar [except for the Gelman(81) quartz filters] and well below the QA Handbook[12] limits of ± 2.8 mg for reweighing unexposed filters. For a given filter type, the filter-to-filter variability in weight change was somewhat lower for the S&S glass filters than for any of the quartz filters or for the Ghia Teflon® filters with the Gelman(81) quartz exhibiting the highest variability. The Gelman(81) filters, while within the ± 2.8 mg specification, exhibited much more dramatic effects than the other filters. Several of these filters gained 2.0 to 2.3 mg from the first weighing to the second weighing and lost 1.9 to 2.1 mg from the fourth weighing to the fifth weighing. The average weight changes over the six weighings are given in the bottom row of Table 2 and ranged from -0.90 mg for the Whatman quartz filters to +0.30 mg for the S&S glass fiber filters.

For comparative purposes the average weight for the ten filters of each type was calculated for each of the six weighings and plotted versus weighing number. The plots are shown for each filter type in Figure 1. The Gelman(81) quartz filters showed the greatest variation in these plots. An examination of the humidity levels in the conditioning room during the test suggested a possible correlation. A strong correlation ($r^2 = 0.88$) was obtained between the average weight of the ten Gelman(81) quartz filters and the relative humidity in the weighing room.

An analysis of covariance that included humidity as a factor was performed on all the data sets, but this analysis showed no evidence of systematic weight losses during the weighing process for any of the filters tested. It was concluded that some random effect associated with each weighing session was the major component of the observed variation in the data over the six weighing sessions. The results with the Gelman(81)

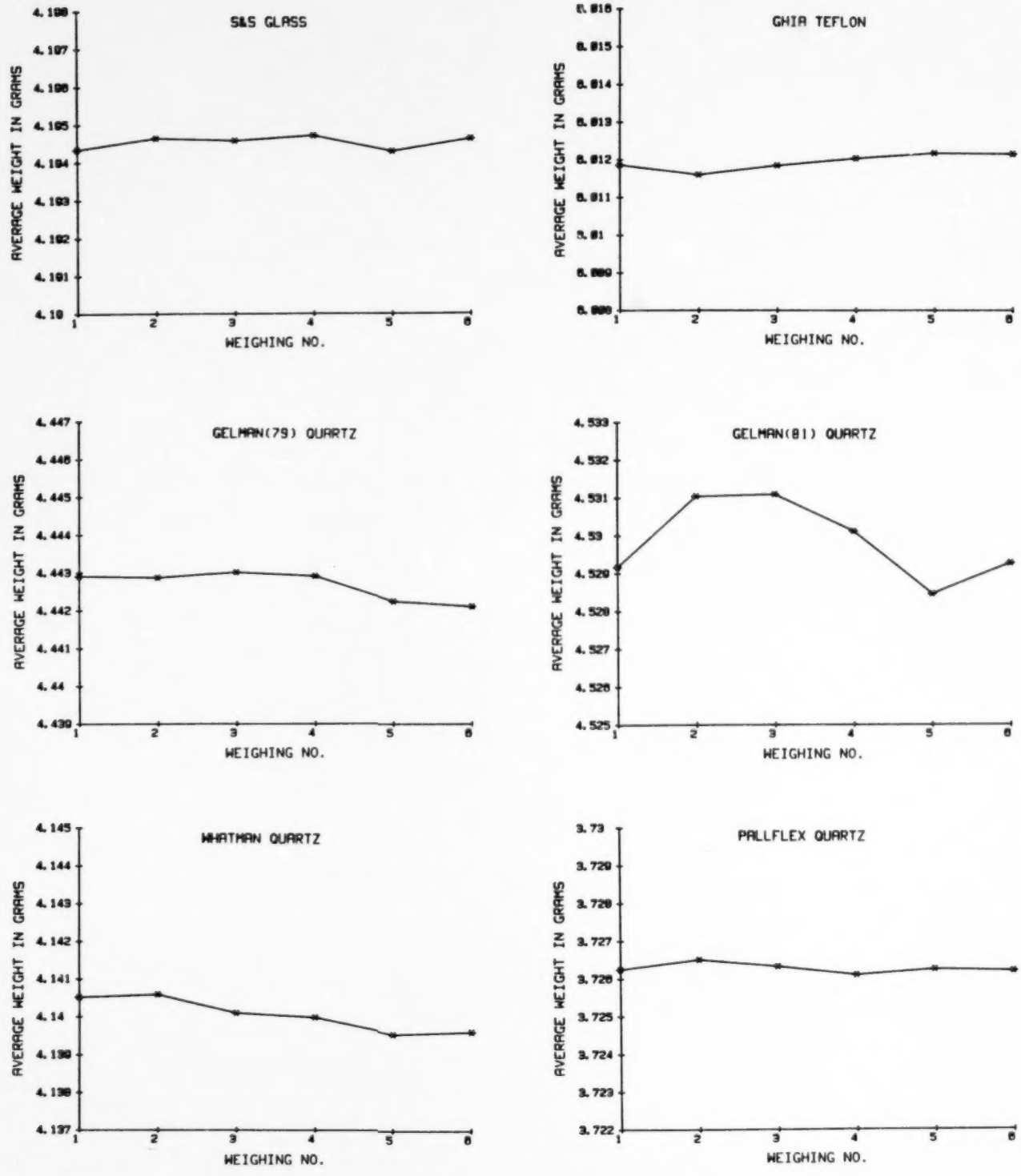

Figure 1. Weighability test - 8 x 10 inch filters.

filters indicate that closer control of relative humidity in the filter conditioning and weighing environment may be necessary for some quartz filters, but further investigation is recommended.

HANDLEABILITY TEST - 8 x 10 INCH FILTERS

The average weight changes between successive weighings before and after mounting of the filters on the high-volume sampler and the average weight changes due to handling and mounting on the sampler are tabulated in Table 3. During this filter mounting test the sampler was turned on and allowed to sample clean air for 5 minutes. It was assumed that the major loss of fiber material from the filters would occur during this sampler start-up period. The 5-minute period also allowed the testing of a large number of filters.

TABLE 3. WEIGHT CHANGES (mg) BETWEEN SUCCESSIVE WEIGHINGS AND BEFORE AND AFTER MOUNTING ON SAMPLER (8 x 10 INCH FILTERS)

		S&S Glass	Gelman(79) Quartz	Gelman(81) Quartz	Whatman Quartz	Pallflex Quartz	Ghia Teflon®
W2-W1:*	Avg.	-0.16	-0.36	-1.13	-0.10	+0.08	-1.26
	S.D.	0.09	0.09	0.56	0.08	0.12	2.11
W4-W3:	Avg.	-0.32	-0.29	-0.31	-0.20	-0.19	+0.16
	S.D.	0.12	0.16	0.40	0.11	0.11	0.16
W3-W2:	Avg.	-0.57	-3.19	-4.31	-2.28	-1.08	+0.50
	S.D.	0.22	0.97	0.92	0.73	0.40	1.74

*W1 indicates the first weighing and so on.

The weight changes between two successive weighings before (W2-W1) and after (W4-W3) mounting of the filters on the sampler and the filter-to-filter variabilities were similar (except for the Ghia Teflon® filters) to

the results obtained in the weighability tests. The Ghia weight changes between the first and second weighings (W2-W1) are suspected to be biased by problems due to static charges not being completely dissipated before the initial weighings. This was, in fact, the first attempt to weigh the Ghia filters and it later became evident that several additional seconds in the balance chamber in close proximity to two static eliminators were needed to dissipate the static charge.

The weight changes (W3-W2) due to handling and mounting on the sampler (with clean air flow for 5 minutes) were substantially higher for the quartz filters than for the S&S glass filters and ranged from -1.1 mg (Pallflex) to -4.3 mg [Gelman(81)] compared to -0.6 mg for the S&S glass fiber filters. For a given filter type, the filter-to-filter variability was also greater than that observed in the weighability tests. The Ghia Teflon® filters gained weight (+ 0.50 mg) with a high filter-to-filter variability.

Once again, for comparative purposes, the average weight for the ten filters of each type was calculated for each of the four weighings and plotted versus weighing number. The plots are shown for each filter type in Figure 2. An analysis of variance was performed on the data using the following model:

$$Wt_{ijk} = \mu + F_i + M_j + e_{ijk} \qquad (1)$$

where Wt_{ijk} is the observed filter weight, μ is an overall mean, F_i is a random effect due to filter type, M_j is a fixed effect due to mounting, and e_{ijk} is the error associated with the observed weight. This analysis revealed that mounting was a significant effect for all filter types except the Ghia Teflon®. The analysis of variance tables are given in Appendix C.

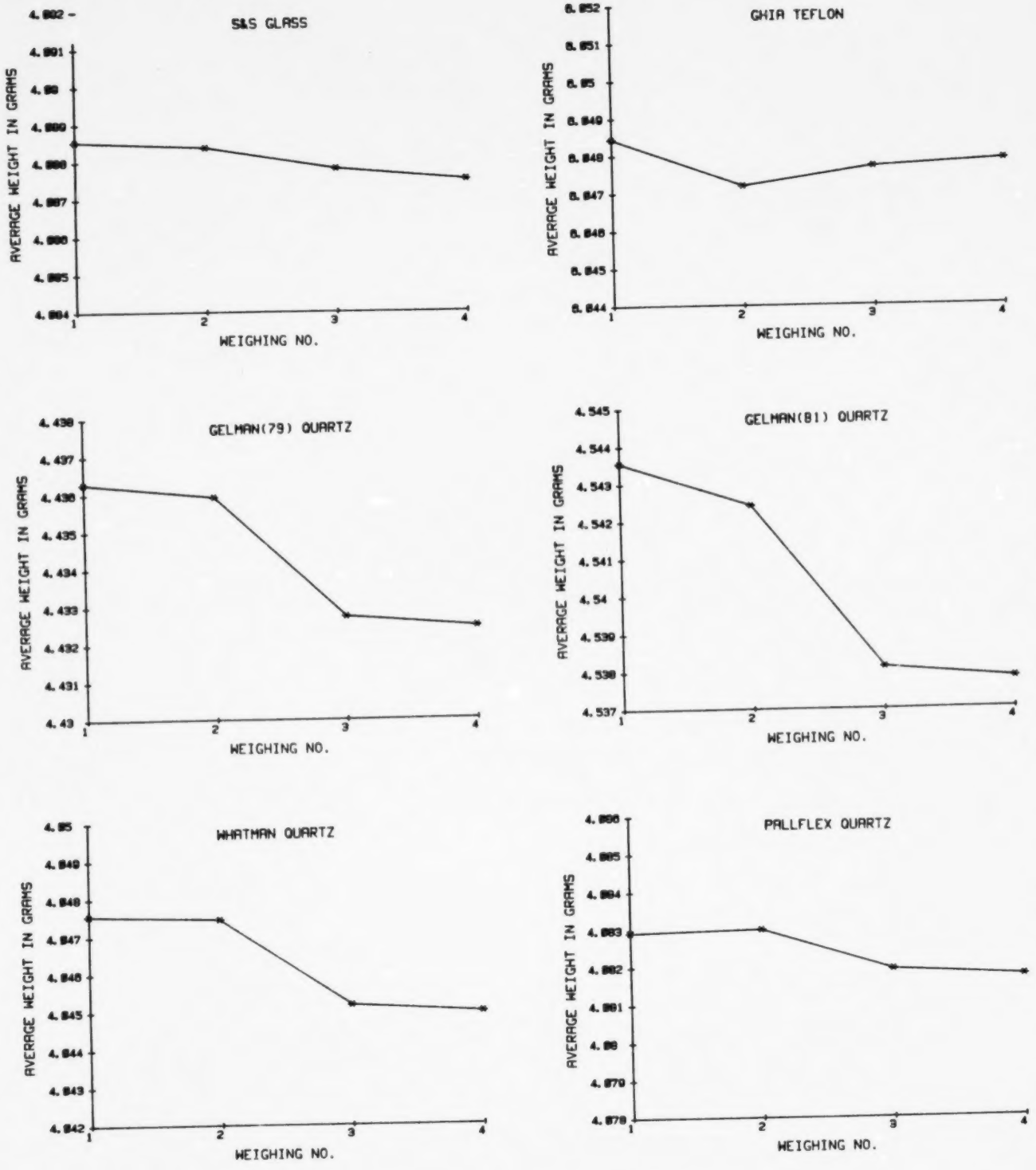

Figure 2. Handleability test - 8 x 10 inch filters.

The average of the first two weighings and the average of the last two weighings were used to estimate the weight changes due to mounting the filters. These estimates appear in Table 4 with estimates of the corresponding errors in mass concentration measurements.

TABLE 4. WEIGHT CHANGES (mg) DUE TO MOUNTING ON SAMPLER (8 x 10 INCH FILTERS)

Filter Type	Wt. Changes (mg)	Corresponding Error in Mass Concentration ($\mu g/m^3$)*
S&S Glass	-0.82	-0.5
Gelman(79) Quartz	-3.51	-2.0
Gelman(81) Quartz	-5.03	-2.8
Whatman Quartz	-2.43	-1.4
Pallflex Quartz	-1.14	-0.6
Ghia Teflon®	+0.054†	+0.03†

*Assuming 24-hour high-volume sample (1800 m^3 sample volume).
†Weight gain observed.

The Ghia Teflon® glass filters exhibited the smallest weight change. The highest weight losses occurred with the quartz filters. The estimated errors in mass concentration for quartz filters were less than the estimated errors due to artifact formation on glass filters for most sampling locations.

Mounting tests of 24-hour duration were performed with two filters of each type, but the results were inconclusive. During the first set of tests, weight gains of up to 9.5 mg were observed for all the filters except the Gelman(81) and visible particle deposits were observed on all of the filters. The clean air plenum and sampler were modified for the second set of tests. All of the filters in this second set gained weight (1.4 to 9.7 mg) but there was no visible evidence of particle deposits on any of the filters. Relative humidity changes between the pre- and post-sampling weighing sessions and artifact formation are factors which may

have confounded the results of these tests.

FIELD COMPARISON TEST - 8 x 10 INCH FILTERS

The measured concentrations of TSP, NO_3^-, and $SO_4^=$ for the two days of sampling when S&S glass fiber filters were used on all six samplers are presented in Table 5. The TSP values were computed as:

$$TSP(\mu g/m^3) = \frac{[\text{wt. after sampling(g)-wt. before sampling (g)}] \times 10^6 \ \mu g/g}{\text{flow rate } (ft^3/min) \times \text{time (min)} \times 0.0283 m^3/ft^3} \quad (2)$$

using the second and third weighings of the filters, the measured sampler flow rates, and the sampling time. The NO_3^- and $SO_4^=$ values were computed in similar fashion using the average analytical result (in µg/filter) for duplicate filter strips.

TABLE 5. TSP, NITRATE, AND SULFATE CONCENTRATIONS (µg/m³) MEASURED WITH HIGH-VOLUME SAMPLERS USING GLASS FIBER FILTERS

	Start of Field Study (Day 0)			End of Field Study (Day 13)		
Sampler No.	TSP	NO_3^-	$SO_4^=$	TSP	NO_3^-	$SO_4^=$
1	66.29	2.98	9.48	91.14	7.10	23.01
2	66.34	2.89	9.41	91.56	7.63	22.67
3	65.46	2.95	9.27	90.20	9.50	23.62
4	63.16	2.85	9.31	87.13	7.53	22.41
5	67.15	3.13	9.91	89.96	7.41	22.77
6	68.75	3.23	9.65	91.32	7.69	23.11
Avg.	66.19	3.01	9.51	90.22	7.81	22.93
S.D.	1.86	0.15	0.24	1.64	0.85	0.42
(R.S.D.)	(2.8%)	(5.0%)	(2.5%)	(1.8%)	(10.9%)	(1.8%)

These results show good agreement among the samplers for TSP, NO_3^-, and $SO_4^=$ measurements except for the day 13 NO_3^- value for sampler 3. The variation in NO_3^- and $SO_4^=$ analyses on the duplicate filter strips was always less than 10 percent.

The TSP concentrations for the 12-day period when all six types of filters were used for sampling are given in Table 6. The corresponding NO_3^- and $SO_4^=$ concentrations are given in Table 7. The concentration values were computed as indicated above.

Each day the highest TSP concentration was obtained with the S&S glass filters, except for day 2 when the Whatman quartz gave the highest value.

TABLE 6. TSP CONCENTRATIONS ($\mu g/m^3$) MEASURED WITH HIGH-VOLUME SAMPLERS USING GLASS, QUARTZ, AND TEFLON® FILTERS

Day No.	S&S Glass	Gelman(79) Quartz	Gelman(81) Quartz	Whatman Quartz	Pallflex Quartz	Ghia Teflon®
1	43.60	34.59	38.64	41.46	36.16	37.84
2	46.38	43.42	41.92	50.60	45.54	44.11
3	95.60	83.75	82.63	87.69	82.84	84.37
4	76.02	63.94	66.42	68.27	60.00	65.71
5	89.11	74.57	86.88	85.46	76.67	72.49*
6	79.92	65.31	58.07	76.87	68.24	67.40*
7	76.51	60.12	71.49	68.85	63.22	63.80
8	36.71	26.94	25.63	32.80	29.02	26.26
9	39.44	33.88	30.39	37.82	30.29	32.57
10	42.82	33.09	34.86	37.64	33.66	34.11
11	36.11	25.55	27.01	31.89	26.10	26.38
12	29.52	23.63	26.47	28.84	24.06	24.09
Avg.	57.64	47.40	49.20	54.02	47.98	48.26

*Plugging of Teflon® filter resulted in significant drop in flowrate.

On two of the days (days 5 and 6) clogging of the Ghia Teflon® filters resulted in a significant drop in the sampler flow rates. Since the TSP concentrations were only 65 to 75 $\mu g/m^3$ on these days, these results suggest that 3.0 μm pore size Teflon® may not be suitable for use on high-volume samplers because of potential overloading problems.

As expected, the glass filters always gave the highest $SO_4^=$ values. The Whatman quartz gave somewhat higher $SO_4^=$ concentrations than the other quartz filters or the Teflon® filter. The highest NO_3^- concentrations were

TABLE 7. NITRATE AND SULFATE CONCENTRATIONS ($\mu g/m^3$) MEASURED WITH HIGH-VOLUME SAMPLERS USING GLASS, QUARTZ, AND TEFLON® FILTERS

Day	S&S Glass		Gelman(79) Quartz		Gelman(81) Quartz		Whatman Quartz		Pallflex Quartz		Ghia Teflon®	
No.	NO_3^-	$SO_4^=$	NO_3^-	$SO_4^=$	NO_3^-	$SO_4^=$	NO_3^-	$SO_4^=$	NO_3^-	$SO_4^=$	NO_3^-	$SO_4^=$
1	2.33	8.61	1.18	4.52	1.49	4.10	2.43	4.82	1.56	4.37	1.11	3.67
2	2.58	7.88	1.64	4.03	2.06	3.45	2.76	4.93	2.16	4.36	1.68	3.62
3	3.08	7.86	0.60	4.36	1.19	4.63	2.28	5.09	0.62	4.90	0.36	4.84
4	1.76	12.68	0.63	5.97	1.04	5.88	1.56	5.85	0.41	5.87	0.22	5.76
5	2.16	8.54	0.68	4.42	1.30	4.53	2.34	5.14	1.05	4.69	0.33*	4.39*
6	2.85	9.41	2.19	3.47	2.26	3.36	3.04	3.98	2.28	3.60	2.07*	3.09*
7	3.18	8.10	0.72	4.47	1.08	4.72	2.38	4.37	0.93	5.09	0.36	4.87
8	1.56	7.51	0.71	2.94	0.92	2.95	1.37	3.78	0.99	3.35	0.44	2.43
9	1.91	9.64	0.39	5.37	0.56	5.41	1.52	6.10	0.25	5.18	0.17	4.99
10	3.91	9.09	0.54	4.88	0.58	4.91	2.80	5.07	0.46	4.91	0.41	4.53
11	3.45	20.03	0.32	11.18	0.30	11.08	2.67	12.35	0.26	11.48	0.21	10.62
12	2.66	9.05	1.07	5.84	0.85	5.76	2.22	5.91	0.84	5.75	0.74	5.57
Avg.	2.62	9.87	0.89	5.12	1.14	5.07	2.28	5.62	0.98	5.30	0.68	4.87

*Plugging of Teflon® filter resulted in significant drop in flowrate.

generally obtained with the glass, but the Whatman quartz gave slightly higher values on four of the 12 sampling days. On the average, the Whatman values for NO_3^- were twice as high as those obtained with the other quartz filters.

The Whatman filters contain a small amount (5 percent) of borosilicate glass, added during the filter manufacturing process. This small amount of glass can apparently cause an increase in artifact formation over what would be expected from filters containing only quartz. Recent work by Appel et al.[13] of the California Department of Health Services, Air and Industrial Hygiene Laboratory, clearly shows this to be the case. Table 8 shows Appel et al.'s laboratory results for $SO_4^=$ and NO_3^- artifact formation potential for the filters used in the present study.

The artifact $SO_4^=$ values shown in Table 8 represent an upper limit obtainable under atmospheric conditions. The low dosage HNO_3 exposures are

intended to simulate atmospheric dosages of HNO_3 and the results show that both glass and Whatman quartz retain essentially 100% of the HNO_3. The high dosage exposures, although not relevant to atmospheric sampling, provide further discrimination among the filters tested.

TABLE 8. RETENTION OF SO_2 AND HNO_3 BY GLASS, QUARTZ, AND TEFLON® FILTERS

Filter Type	SO_2 Retention, Mean Artifact Sulfate ($\mu g/m^3$)*	HNO_3 Retention, Mean Retention (%) Low Dosage†	High Dosage‡
S&S Glass	12.6 ± 0.3	>99.2	44.8 ± 5.8
Gelman(79) Quartz	0.59 ± 0.04	33.8 ± 4.1	3.9 ± 0.6
Gelman(81) Quartz	0.73 ± 0.06	78.7 ± 7.5	7.4 ± 1.4
Whatman Quartz	5.16 ± 0.61	>99.2	30.2 ± 2.0
Pallflex Quartz	1.47 ± 0.17	78.4 ± 6.7	8.7 ± 1.0
Ghia Teflon®	0.061 ± 0.001	1.5 ± 0.9	0.5 ± 0.2

*24-hour exposure of clean 47 mm filters to 0.10 ppm SO_2 @ 37.4 Lpm, 21° C, and 80% R.H. (SO_2 dosage: 13900 µg).

†2-hour exposure of clean 47 mm filters to 12.5 ppb HNO_3 @ 37.4 Lpm, 21° C, and 51% R.H. (HNO_3 dosage: 146 µg).

‡6-hour exposure of clean 47 mm filters to 70 ppb HNO_3 @ 37.4 Lpm, 21° C, and 51% R.H. (HNO_3 dosage: 2426 µg).

The results of the present field study are in excellent agreement with the laboratory results of Appel et al. The laboratory artifact formation studies indicate that glass filters should give the highest NO_3^- and $SO_4^=$ values, followed by the Whatman quartz. Teflon® filters should give the lowest values (negligible artifact) and the other quartz filters should give intermediate values but relatively close to those observed with Teflon®. The results of the current field study, as shown in Table 7, show exactly that. The artifact effects with the Whatman quartz filters appear to be more dramatic for NO_3^- than for $SO_4^=$, but even this might be expected, since both the Whatman quartz and glass filters retained about 100% of the HNO_3 in the laboratory study.

The average TSP concentrations observed in the 12-day field study were corrected for artifact effects and handling effects and the results are shown in Table 9. The artifact NO_3^- and $SO_4^=$ values were calculated by assuming that the average NO_3^- and $SO_4^=$ concentrations observed with the Ghia Teflon® are the "true" average concentrations. Subtraction of these "true" NO_3^- and $SO_4^=$ concentrations from the averages observed with the other filter types results in the artifact values. The above assumption may be invalid for NO_3^- since loss of particulate NO_3^- may be occurring on the Ghia Teflon® filters. The corrections for handling effects are taken from Table 4 and are based on the weight losses observed in the mounting and 5-minute sampling tests. The results shown in Table 9 indicate that the differences in the observed TSP averages for the various filter types can be accounted for reasonably well by artifact and filter handling effects.

TABLE 9. AVERAGE TSP CONCENTRATIONS ($\mu g/m^3$) CORRECTED FOR ARTIFACT AND HANDLING EFFECTS*

	S&S Glass	Gelman(79) Quartz	Gelman(81) Quartz	Whatman Quartz	Pallflex Quartz	Ghia Teflon®
TSP (observed)	57.6	47.4	49.2	54.0	48.0	48.3
Artifact NO_3^- and $SO_4^=$	6.9	0.5	0.7	2.4	0.7	0.0
TSP (corrected for artifact)	50.7	46.9	48.5	51.6	47.3	48.3
Handling losses	0.5	2.0	2.8	1.4	0.6	0.0
TSP (corrected for artifact and handling)	51.2	48.9	51.3	53.0	47.9	48.3

*See text for necessary assumptions.

The results of the 12-day field test were subjected to a more extensive statistical analysis. An analysis of variance of the TSP concentration data using the model:

$$TSP_{ijk} = \mu + D_i + S_j + F_k + SF_{jk} \quad (3)$$

where TSP_{ijk} is the observed concentration, μ is an overall mean, D_i is a random effect due to the day the sample was taken, S_j is a random effect due to the sampler used, F_k is a random effect due to filter type, and SF_{jk} is an interaction effect due to samplers interacting with filter types. For all cases, the model explained 99% of the variation in the data. All terms of the model were significant in all cases.

A Duncan[14] multiple range test was applied to the mean TSP concentrations obtained with the six filter types to determine whether the observed means differed significantly. This test revealed groupings that were expected (see Table 10). The filters with glass fibers (S&S glass and Whatman quartz) were in statistically different groups and yielded higher mean TSP values than filters without glass fibers. The filters made exclusively of quartz (both Gelmans and the Pallflex) and Teflon® were tested as not different from each other. The mean TSP concentrations were then adjusted for artifact NO_3^- and $SO_4^=$ effects (as described earlier) and the same analysis repeated. The filters with glass fibers (S&S glass and Whatman quartz) were now grouped together. A further adjustment was introduced for the average weight losses due to mounting filters on the sampler. The analysis was repeated again and several changes in the groupings and order were observed. The Whatman quartz filter yielded the highest mean TSP concentrations and was grouped with the Gelman(81) quartz and S&S glass filters. The Gelman(79) quartz, Ghia Teflon®, and Pallflex quartz filters were grouped together.

TABLE 10. GROUPINGS DEFINED BY DUNCAN'S MULTIPLE RANGE TEST (x = 0.05)

No Corrections

Filter Type	Mean Concentration (μg/m³)	Group*
S&S Glass	57.64	A
Whatman Quartz	54.02	B
Gelman(81) Quartz	49.20	C
Ghia Teflon®	48.26	C
Pallflex Quartz	47.98	C
Gelman(79) Quartz	47.40	C

Corrected for Artifacts

Filter Type	Mean Concentration (μg/m³)	Group*
Whatman Quartz	51.61	A
S&S Glass	50.70	A
Gelman(81) Quartz	48.49	B
Ghia Teflon®	48.26	B
Pallflex Quartz	47.24	B
Gelman(79) Quartz	46.85	B

Corrected for Artifacts and Handling

Filter Type	Mean Concentration (μg/m³)	Group*
Whatman Quartz	52.98	A
Gelman(81) Quartz	51.30	A
S&S Glass	51.16	A
Gelman(79) Quartz	48.82	B
Ghia Teflon®	48.29	B
Pallflex Quartz	47.88	B

*Means with the same group letter are not significantly different.

HANDLEABILITY TEST - 102 mm FILTERS

In the first test using only Ghia Teflon® filters, the two initial weighings gave an average difference of -0.02 mg ± 0.07 mg (one standard deviation). The weight changes for the ten filters ranged from -0.19 mg to + 0.05 mg. The two weighings after placement on the 4 cfm sampler gave

comparable results, with an average weight change of + 0.03 mg ± 0.06 mg. A comparison of the averages of the initial and final weighings showed that all ten filters gained weight when placed on the sampler. An average weight gain of 0.28 mg ± 0.14 mg was observed, essentially repeating what was observed with the 8 x 10 inch filters. It is not clear whether this observed weight gain is attributable to the filter itself, the placement of the filter on the sampler, or particle contamination in the clean air system.

In the second test all six filter types were examined. The average weight changes between successive weighings before and after mounting of the filters on the sampler and the average weight changes due to handling and mounting on the sampler are tabulated in Table 11 and shown graphically in Figure 3.

These results for the 102 mm filters are comparable to those obtained for the 8 x 10 inch filters after adjustment for relative filter size (8 x 10 inch filters are 6.3 times larger in area than the 102 mm filters). The averages of the initial and final weighings were used to estimate the weight changes due to mounting and the corresponding errors in mass concentration. The results are given in Table 12. The S&S glass filters exhibited the smallest weight loss due to mounting. As in the case of the 8 x 10 inch filters, the 102 mm quartz filters exhibited the highest weight losses. The corresponding errors in mass concentration estimated for the 102 mm filters were similar (0.5 to 3.1 $\mu g/m^3$) to those estimated for the 8 x 10 inch filters (0.5 to 2.8 $\mu g/m^3$). Once again, the Ghia Teflon® filters showed a slight weight gain equivalent to 0.2 $\mu g/m^3$.

TABLE 11. WEIGHT CHANGES (mg) BETWEEN SUCCESSIVE WEIGHINGS AND BEFORE AND AFTER MOUNTING ON SAMPLER - (102 mm FILTERS)

		S&S Glass	Gelman(79) Quartz	Gelman(81) Quartz	Whatman Quartz	Pallflex Quartz	Ghia Teflon®
W2-W1:*	Avg.	+0.079	-0.073	-0.178	-0.086	-0.012	+0.009
	S.D.	0.094	0.070	0.108	0.115	0.047	0.085
W4-W3:	Avg.	-0.056	-0.079	0.000	-0.011	-0.017	+0.027
	S.D.	0.064	0.068	0.058	0.059	0.087	0.076
W3-W2:	Avg.	-0.130	-0.436	-0.139	-0.133	-0.066	+0.037
	S.D.	0.086	0.124	0.100	0.059	0.068	0.105

*W1 indicates the first weighing and so on.

TABLE 12. WEIGHT CHANGES (mg) DUE TO MOUNTING ON SAMPLER (102 mm FILTERS)

Filter Type	Wt. Changes (mg)	Corresponding Error in Mass Concentration ($\mu g/m^3$)*
S&S Glass	-0.119	-0.7
Gelman(79) Quartz	-0.512	-3.1
Gelman(81) Quartz	-0.228	-1.4
Whatman Quartz	-0.181	-1.1
Pallflex Quartz	-0.080	-0.5
Ghia Teflon®	+0.080†	+0.2†

*Assuming 24-hour 4 cfm sampler (163 m^3 sample volume).
†Weight gain of 0.08 mg observed.

WEIGHABILITY AND HANDLEABILITY TESTS - 37 mm FILTERS

Five filters of each of the four types of quartz filters were subjected to various handling operations. The average weight changes between successive handling operations are listed in Table 13 and shown graphically in Figure 4.

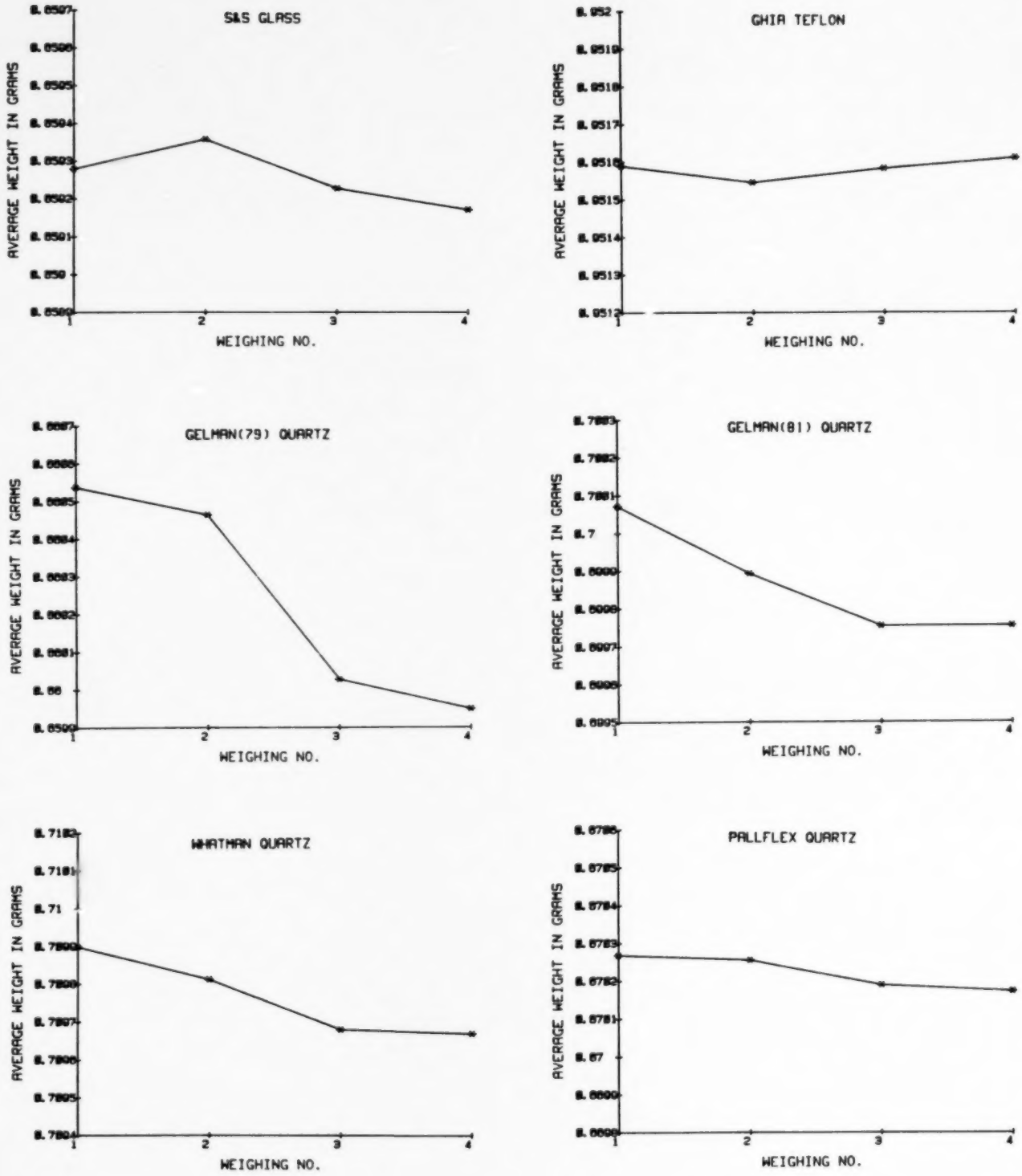

Figure 3. Handleability test - 102 mm filters.

TABLE 13. WEIGHT CHANGES (mg) BETWEEN SUCCESSIVE HANDLING OPERATIONS (37 mm FILTERS)

Handling Operation*		Gelman(79) Quartz	Gelman(81) Quartz	Whatman Quartz	Pallflex Quartz
A	Avg.	+0.003	-0.038	-0.004	0.000
	S.D.	0.012	0.041	0.011	0.004
B	Avg.	-0.042	-0.018	-0.020	-0.041
	S.D.	0.008	0.008	0.010	0.033
C	Avg.	-0.008	-0.036†	-0.008	-----ǂ
	S.D.	0.007	0.007†	0.008	-----ǂ
D	Avg.	+0.004	+0.098	+0.012	+0.007
	S.D.	0.004	0.008	0.003	0.007
E	Avg.	+0.018	-0.040	+0.031	+0.001
	S.D.	0.034	0.012	0.011	0.029
All Operations					
Max. Avg. Wt. Diff. ($\mu g/m^3$)**		0.050 (2.1)	0.098 (4.1)	0.043 (1.8)	0.041 (1.7)

*Handling Operations:

A - Same day weighing (5/10/82 am and 5/10/82 pm).
B - Placement in nylon cassette and next day weighing (5/11/82 am).
C - 6-Foot drop test and same day weighing (5/11/82 pm).
D - Next day weighing (5/12/82).
E - Mailing test and weighing (6/4/82).

†No drop test; but weighed.
ǂNo drop test; not weighed.
**Assuming 24-hour dichotomous sampler (24 m^3 sample volume).

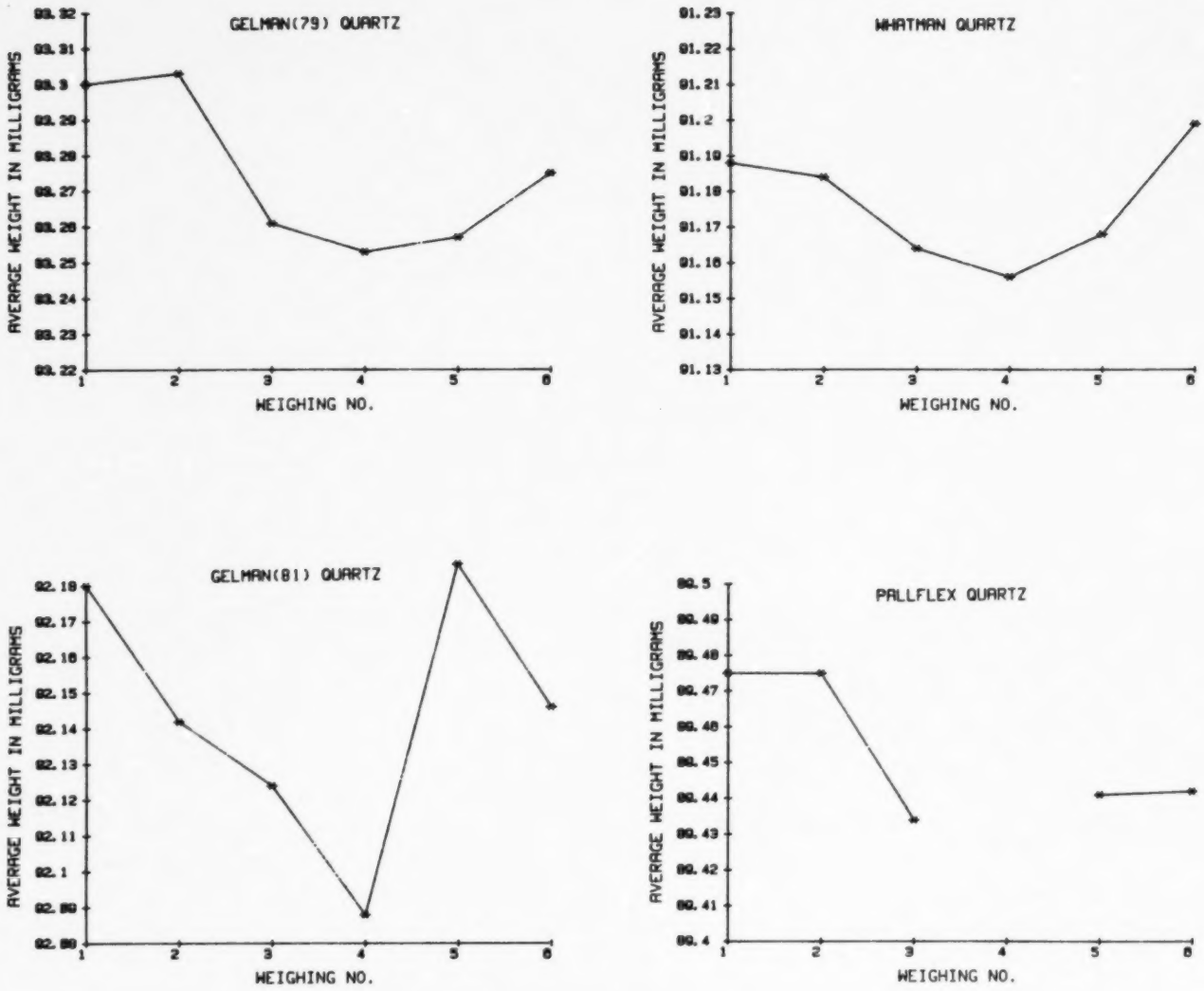

Figure 4. Handleability test - 37 mm filters.

Placement of the filters in the nylon cassettes used in the Sierra Model 244 dichotomous sampler followed by reweighing of the filters on the next day resulted in statistically significant losses for all four types of quartz. For the Gelman(81) filters, handling operations C (same day weighing, without drop test), D (next day weighing) and E (mailing test) all resulted in statistically significant effects. The rather large weight gain (0.098 mg) observed for the Gelman(81) filters for operation D is probably due in part to a increase in humidity (by 4% RH) in the conditioning room from one day to the next. For the Whatman filters, handling operations D and E also resulted in small but statistically significant effects.

The maximum average weight differences for each quartz filter type over all operations were computed and are shown at the bottom of Table 13. The corresponding mass concentration (in $\mu g/m^3$) assuming a 24 m^3 sampling volume is also indicated. As mentioned above, the 0.098 mg change shown for the Gelman(81) filters includes the effect of relative humidity and would be expected to be lower with better humidity control. The approximate 2 $\mu g/m^3$ obtained with the other quartz filters appears to be within the limits of acceptable error.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

1. Weight changes observed during repeated weighings of 8 x 10 inch and 102 mm glass, quartz, and Teflon® filters in this study were all well below the QA Handbcok[12] limits of ± 2.8 mg for reweighing unexposed filters. A statistical analysis of the test data showed no evidence of systematic weight loss during the weighing process for any of the filters tested.

2. Weight losses due to mounting of the 8 x 10 inch and 102 mm filters on particle samplers were observed for both glass and quartz filters. A statistical analysis of the test data revealed that mounting was a significant effect for all filter types tested except the Ghia Teflon®. The estimated errors in corresponding mass concentration measurements were less than 3 $\mu g/m^3$.

3. Ambient TSP, NO_3^-, and $SO_4^=$ concentrations measured during this study using quartz and Teflon® filters on high-volume samplers were lower than those measured using glass fiber filters. The observed differences in TSP measurements could be explained in part by the increased artifact NO_3^- and $SO_4^=$ on filters containing glass fibers (S&S glass and Whatman quartz). The Whatman quartz filters gave ambient NO_3^- concentrations that were twice as high as those obtained with the other quartz filters. Sulfate values for the Whatman quartz were also somewhat higher.

4. The humidity in the filter conditioning and weighing environment has an apparent effect on filter weights, more so for the quartz filters than for the glass filters. The correlation between filter weight and humidity for the Gelman(81) quartz filters suggests that closer control of humidity

during conditioning and weighing might be advantageous for this, and perhaps other quartz filters, but further investigation is recommended.

5. The Ghia Teflon® filters exhibited a tendency to gain weight upon repeated weighings, even after mounting on the samplers. Although the observed weight gains were small over the time periods involved in this study, this phenomenon warrants further investigation. (During the latter stages of this study, similar effects over longer time periods have been reported by Rockwell[15] and Aerovironment, Inc.[16]). The 8 x 10 inch Ghia Teflon® filters also had a tendency to clog during ambient sampling at TSP concentrations around 65 to 75 $\mu g/m^3$.

6. Based on the results of this study, the use of 8 x 10 inch and 102 mm quartz filters as collection substrates on high- and medium-volume particle samplers appears to be feasible. Special care during weighing, handling, and mounting operations is necessary when using quartz filters. The use of filter cassette holders, designed to facilitate installation of filters at field sites, is recommended.

7. Although the results of this study suggest that the use of 37 mm quartz filters as collection substrates on dichotomous samplers might be feasible, further investigation is recommended. (A recent study by EMSL's Environmental Monitoring Division[16] indicate that the edge of 37 mm quartz filters tear during mounting of filter cassette holders in the sampler. A redesign of the cassette holder might solve this problem.)

8. Close control of humidity levels in the filter conditioning and weighing environment is recommended when quartz filters are used. Filters used with medium-volume samplers should be weighed on a 5-place analytical balance.

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APPENDICES

APPENDIX A - CALIBRATION AND PRECISION CHECKS FOR 5-PLACE METTLER BALANCE

TABLE A-1. 5-PLACE METTLER BALANCE (EPA 032383) - CALIBRATION CHECK WITH CLASS S-1 WEIGHTS

Class S-1 Weight	Balance Reading
5 g	4.99987
4 g	3.99982
3 g	2.99996
2 g	1.99988
1 g	1.00000

TABLE A-2. 5-PLACE METTLER BALANCE (EPA 032383) - PRECISION CHECKS WITH 5-GRAM WEIGHT

	No. of Weighings	Average Weight	Standard Deviation
Repetitive weighings without removal of balance weights or 5 g standard weight	10	4.999964	0.000032
Repetitive weighings with removal of weights; no zero adjustment	10	4.999918	0.000047
Repetitive weighings with removal of weights; zero adjustment after each weighing	10	4.999938	0.000046

TABLE A-3. 5-PLACE METTLER BALANCE (EPA 032383) - PRECISION CHECKS WITH 1-GRAM WEIGHT

	No. of Weighings	Average Weight	Standard Deviation
Repetitive weighings with removal of weights; zero adjustment after 5 weighings	10	1.000131	0.000026
Repetitive weighings with removal of weights; zero adjustment after each weighing	10	1.000113	0.000026

APPENDIX B. HIGH-VOLUME SAMPLER CALIBRATION AND FLOW RATE AUDITS

TABLE B-1. HIGH-VOLUME CALIBRATION DATA

$Y = A + BX$

Y = Flow rate, cfm
X = Dickson reading, % scale
A = Intercept
B = Slope

Sampler No.	A	B	r^2
1	-12.00	1.6254	0.9983
2	- 8.36	1.5151	0.9981
3	- 2.65	1.3990	0.9996
4	- 8.35	1.6419	0.9971
5	- 1.98	1.2558	0.9932
6	- 1.80	1.2439	0.9990

TABLE B-2. HIGH-VOLUME FLOW RATE AUDITS

Audit No.		Sampler No. 1	2	3	4	5	6
1	Meas. value	44.89	43.18	44.92	40.91	43.23	44.22
	Audit value	45.78	45.84	45.32	43.97	44.71	45.46
	% Diff.	-1.94	-5.80	-0.88	-6.96	-3.31	-2.73
2	Meas. value	46.51	46.18	44.92	45.01	44.80	44.85
	Audit value	45.38	46.07	45.98	43.82	44.83	45.49
	% Diff.	+2.49	+0.24	-2.31	+2.72	-0.07	-1.41
3	Meas. value	47.33	46.94	44.92	44.19	45.43	44.22
	Audit value	46.44	46.30	46.47	44.37	45.61	45.98
	% Diff.	+1.92	+1.38	-3.34	-0.41	-0.39	-3.83
4	Meas. value	46.92	46.18	50.51	47.06	45.74	45.47
	Audit value	46.41	46.53	46.53	44.43	45.61	46.09
	% Diff.	+1.10	-0.75	+8.55	+5.92	+0.29	-1.35

APPENDIX C. ANALYSIS OF VARIANCE-HANDLEABILITY DATA (8 x 10 INCH FILTERS)

TABLE C-1. ANALYSIS OF VARIANCE-HANDLEABILITY DATA (8 x 10 INCH FILTERS)

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	PR >F
Filter Type: Gelman(81) Quartz		R^2 = 0.999816			
Filters	9	0.07027095	0.007807883	17433.69	0.0001
Mounting	1	0.00025291	0.00025291	564.70	0.0001
Error	29	0.00001299	0.00000045		
Total	39	0.07053685			
Filter Type: Gelman(79) Quartz		R^2 = 0.999983			
Filters	9	0.55570611	0.061745123	99999.99	0.0000
Mounting	1	0.00012313	0.00012313	367.18	0.0001
Error	29	0.00000972	0.00000034		
Total	39	0.55583896			
Filter Type: S&S Glass		R^2 = 0.999991			
Filters	9	0.12742956	0.014158840	99999.99	0.0000
Mounting	1	0.00000650	0.00000650	157.59	0.0001
Error	29	0.00000120	0.00000004		
Total	39	0.12743726			
		R^2 = 0.999925			
Filters	9	0.66162561	0.073513957	42948.04	0.0001
Mounting	1	0.00000002	0.00000002	0.01	0.9103
Error	29	0.00004964	0.00000171		
Total	39	0.66167527			
Filter Type: Whatman Quartz		R^2 = 0.999986			
Filters	9	0.36368758	0.04040973	99999.99	0.0000
Mounting	1	0.00005907	0.00005907	327.62	0.0001
Error	29	0.00000523	0.00000018		
Total	39	0.36375188			
Filter Type: Pallflex Quartz		R^2 = 1.000000			
Filters	9	9.35988246	1.039986940	99999.99	0.0000
Mounting	1	0.00001288	0.00001288	170.00	0.0001
Error	29	0.00000220	0.00000008		
Total	39	9.35989754			